Generation of 1.2-nJ, 62-fs, chirp-free pulses directly from a Yb-doped fiber oscillator

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1.2-nJ, 62-fs, linear-chirp-free pulses are generated directly from a mode-locked fiber oscillator through optimized interaction of second- and third-order dispersion with self-phase modulation.

I. Introduction

The broad impact of the development of compact, highly robust mode-locked fiber lasers for scientific and industrial applications is uncontested. The standard operation of these lasers is to generate (approximately) linearly chirped pulses, which are de-chirped or shaped in more advanced setups outside of the cavity [1]. Pulse compressibility close to its transform limit is determined by a complex interaction of dispersion, filter bandwidth or gain filtering, saturable absorber and nonlinearity level as well as the distribution of these factors throughout the cavity. Different techniques for de-chirping range from the use of diffraction gratings [2], prisms [3], a combination of prism and grating pairs [4], chirped mirror compressors [5], optical fiber grating compressor [6], photonic crystal fibers [7], compensation of TOD with self-phase modulation (SPM) [8] and more complex techniques that incorporate spatial light modulators [9]. However, despite a decade of intense development of fiber oscillators, little progress has been made in terms of generation of nearly transform-limited pulses directly from the laser. Achieving this would be desirable not only from a practical point of view, but even more importantly due to advanced understanding and control of the intra-cavity dynamics that is required. Advanced tailoring of pulse shaping mechanisms inside oscillator cavities is likely to make fiber laser systems more compact as well as a vehicle for studying the still not completely understood dynamics of mode-locking.

Here, we report on the achievement of such tailored intra-cavity dynamics to generate linear chirp-free pulses directly from the cavity. To this end, we optimize the level of second and third order dispersion (GVD & TOD) and by incorporation of a second pair of diffraction gratings. We report generation of 62-fs pulses with 1.2-nJ, which is sufficient for various applications, e.g., for multi-photon microscopy or enough to comfortably seed an amplifier. To the best of our knowledge, these are the shortest pulses directly generated from Yb-based fiber laser oscillator, improving previous reports of generation of 74-fs pulses from a micro resonator [10].

II. Simulation and Experiment Results

The laser cavity was designed and experimental optimized through numerical simulations, which match the experiments well.

A. Simulations

Our numerical simulation is based on solving a general form of the nonlinear Schrödinger equation with a split-step method, the same model used by [11]. The cavity setup is indicated in Fig. 1 (a). Fig. 1(b) shows the spectral and temporal evolution of the pulse with parameters that match experiments. A 55-fs parabolic pulse with 27-nm spectral bandwidth evolves to ~3-ps in the 1st diffraction grating compressor (DG). Then, the negatively chirped pulse is partially de-chirped in the following 380 cm-long normal-dispersion SMF with negligible spectral compression, before it inters the gain fiber with a negative chirp that can be compensated by 16-cm of the gain fiber. This configuration helps to overcome gain narrowing: The spectral width goes down to ~14 nm in the beginning of the gain fiber and then increases to 57 nm at the end of it through self-similar amplification. Artificial SA (nonlinear polarization evolution, NPE) further shapes the pulse to shorter pulse width and narrower spectral width (~27 nm). Finally it is de-chirped in the 2nd compressor (DG2) to its original parameters, satisfying the periodicity requirement. A second output is taken here, where the pulse is 55 fs-long.

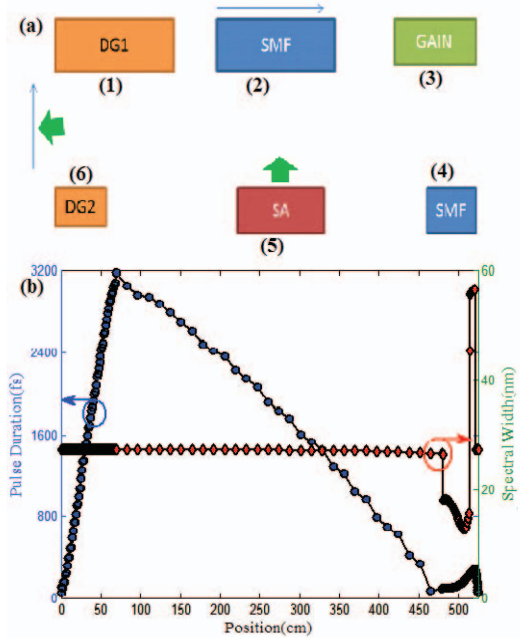

Fig. 1. (a) Schematic representation of the simulation setup. (b) The corresponding pulse evolution showing pulse duration and bandwidth.

B. Experimental results

We designed our oscillator matching the simulated cavity (Fig. 2), which has a 35 cm-long Yb-gain fiber, 380 cm-long SMF, two compressors with 300 and 600 grooves/mm gratings, a coupler with 5% output, optical an isolator followed by a WDM. The oscillator is pumped by two 980-nm pump diodes with up to 800 mW.

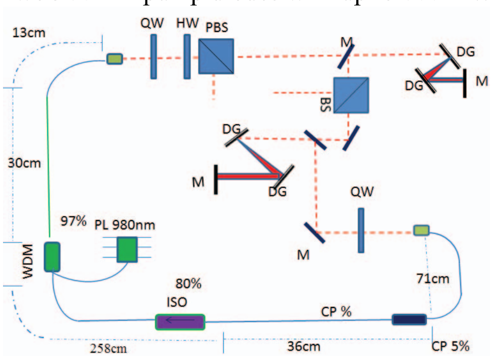

Fig. 2. Schematic diagram of experimental setup.

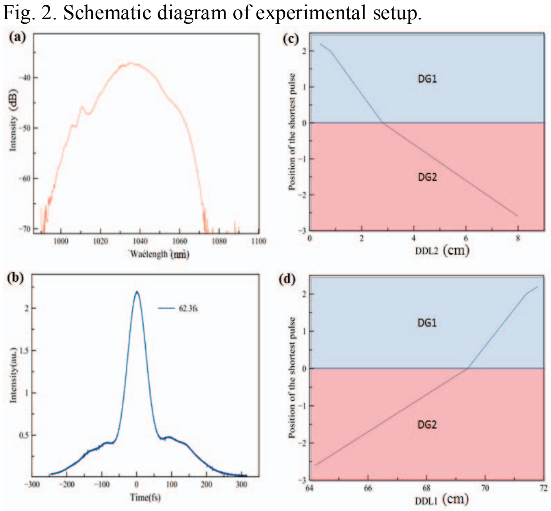

Fig. 3. (a) Measured optical spectrum and (b) measured autocorrelation signal for the port between the DDLs. Position of the shortest pulse as a function of dispersion from (c) DDL2 and (d) DDL1.

Next, we describe the experimental methodology used to tune the experimental conditions and match the simulated results. The net cavity dispersion is scanned from -8000 ps^2 to + 5000 ps^2 to obtain shortest pulses at the output port between the two DDLs. Stable and self-starting cavity exhibits a number of pulsing dynamics that ranges from a stretched pulse, similariton, dissipative soliton to effective soliton regime, and from usual pulse shapes to noise like pulses. The cavity dynamics is adjusted such that it generates pulses, which are shortest at the output port (BS port) between the two grating compressors. First output is taken before DDL2 just after the PBS and compressed outside the cavity. The net GVD of the oscillator is adjusted to generate a pulse that can be compressed well. Next, DDL1 is adjusted with a dispersion value that matches the external compressor and then DDL2 is adjusted so that the net GVD of the cavity remains the same. With this procedure, we generate 62-fs, 1.2-nJ pulses with a spectral width of 32 nm as shown in Fig. 3(a). The transform limited pulse duration is ~47 fs. Fig. 3c and 3d show the position of the shortest pulse for different combinations of the two compressors with the same net cavity dispersion. The position indicated by zero is free space between them. We attribute the small deviation of transform to uncompensated nonlinear phase accumulation, higher-order dispersion and possibly a small residual spatial chirp introduced by the DDLs [7-10]. RF spectral measurement shows 70-dB signal-to-noise ratio, which is comparable to oscillators with single DDL.

III. Conclusions

We able to generate 1.2-nJ, 62-fs, linear-chirp-free pulse from a custom-designed fiber oscillator without requiring external compression. The cavity dynamics were first designed numerically according to clear algorithm and the methodology for finding the experimentally matching condition has been outlined. These results constitute a step forward in theoretical design of custom oscillators that can exhibit almost any desired dynamics. Further efforts can incorporate other dynamics such as extreme nonlinear broadening for ultrashort pulses, intra-cavity Cherenkov radiation generation for broadband spectral tenability and even intra-cavity harmonic wave generation, among others.

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